3D Digitization for Research, Education, and Creativity

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Goals for Today

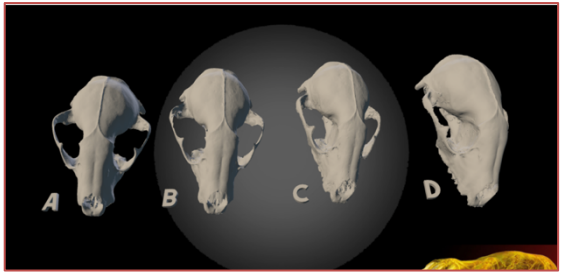
- What and why to digitize
- How to digitize – choosing the right path to 3D
- 3D digitization technologies available @ IU
  - 3D Software modeling
  - Hardware-based volumetric
  - Hardware-based surface scanning
  - Software-based photogrammetry
  - Post-processing workflows for all digitization technologies
- 3D digitization in a broader context – a comprehensive workflow
- Results & Applications of 3D digitization
- Conclusions & How to apply 3D digitization to your work

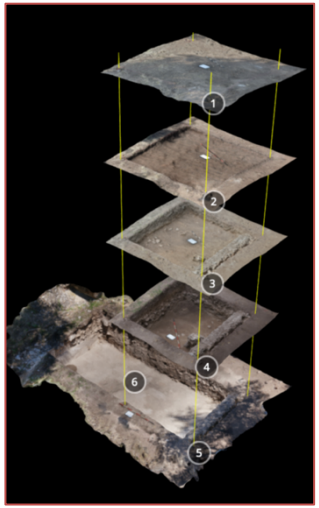
3D Digitization – What & Why?

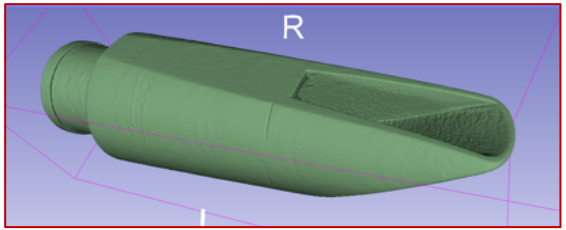
3D Digitization – What?

Common Application Areas

- Cultural Heritage
- Natural History
- Architecture & Design
- Art / Creative Activities
- Engineering
- Medicine & Anatomy
- GIS & Archaeology







3D Digitization – Why?

- Digital preservation* and documentation
  - Rare, valuable and delicate collections (changing by accident or by nature)
  - Time-varying structures and sites (changing on purpose, by humans)
  - * (supplementing physical preservation)
- Enable novel research or creativity
  - Acquire and analyze geometric or spatial data
  - Creative activities & artistic interpretation
- Easier access and broader dissemination
  - Research & Scholarship
  - Teaching & Learning
  - Community engagement

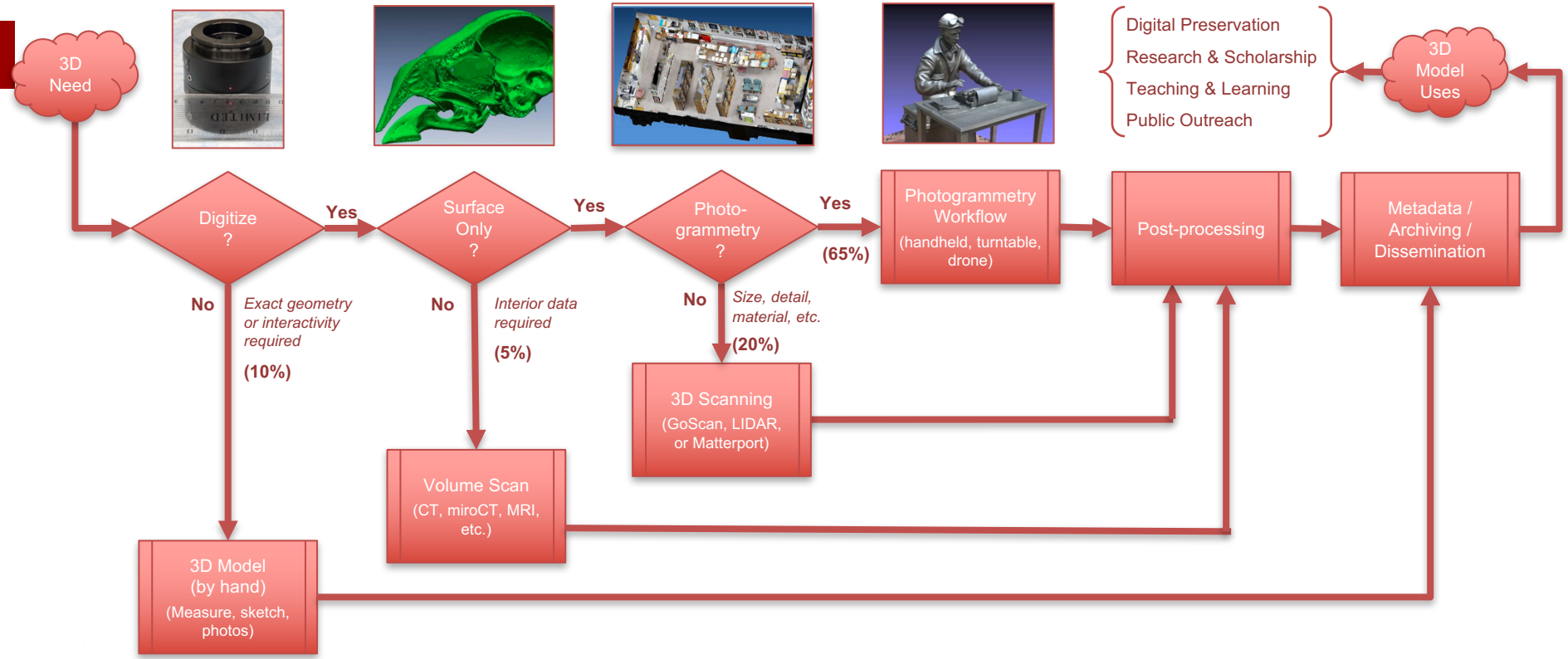
3D Digitization – Why?

3D Digitization – Why?

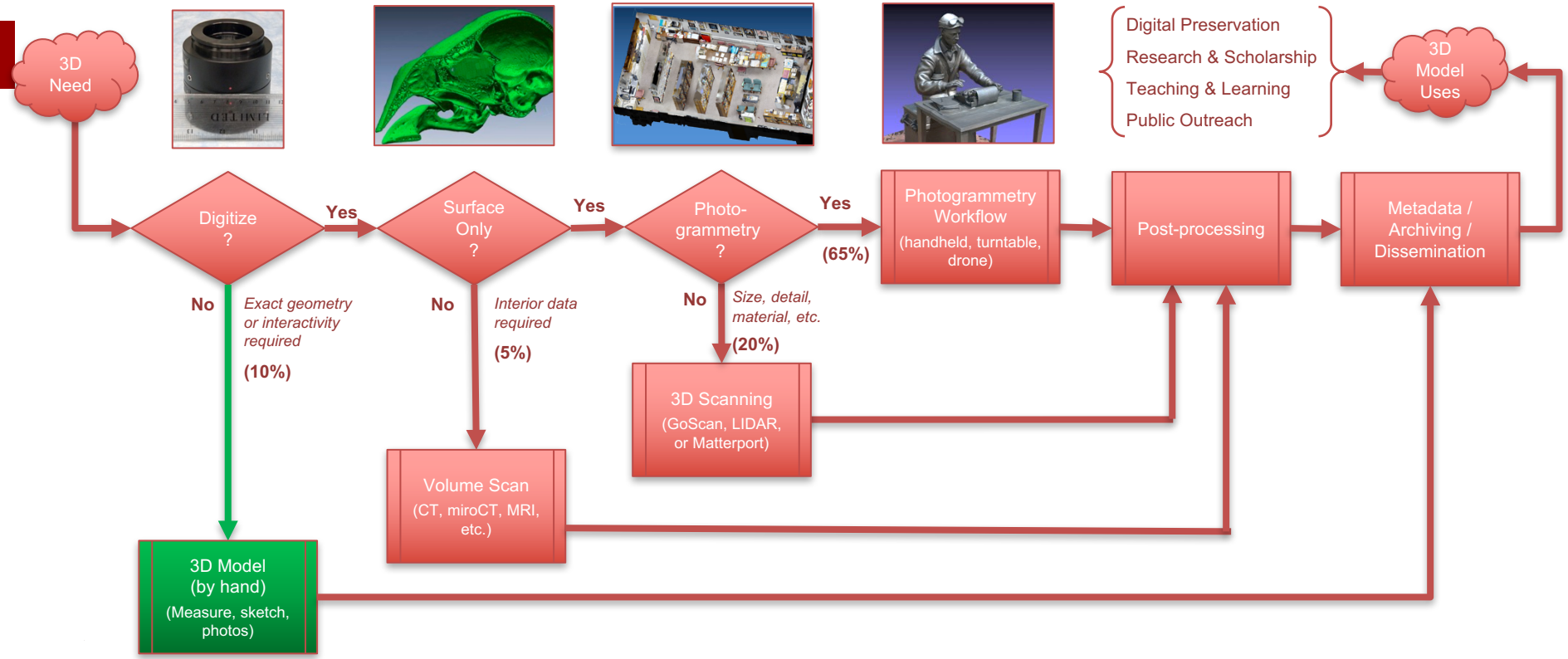
Cultural Terrorism

3D Digitization – How?

3D Digitization – How? (Choosing between techniques)

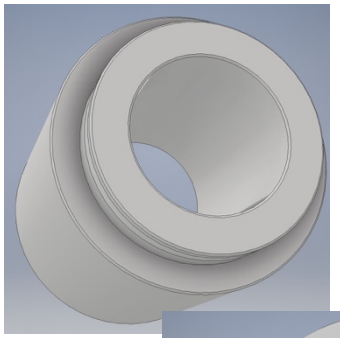


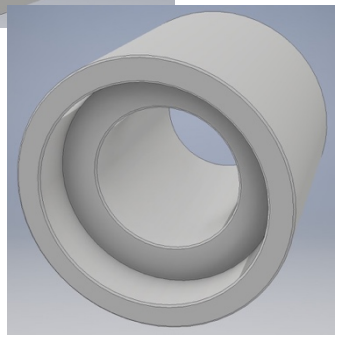
3D Digitization – How? (Choosing between techniques)



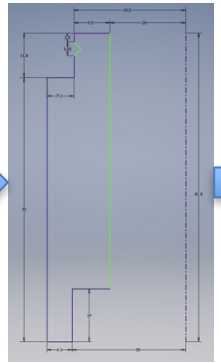
3D Modeling Option

- Measure and model with software tools
- Lots of software options
- Requires skills with select modeling packages
- Example Project: Microscope Lens Extension

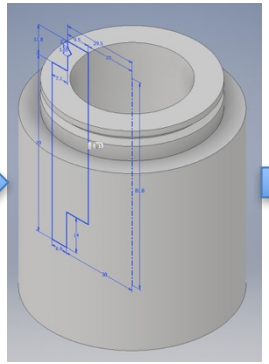




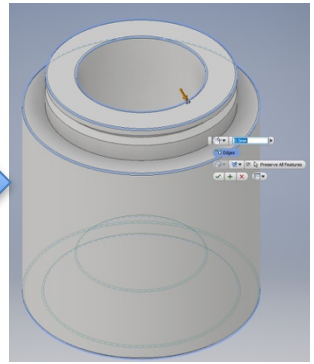
Measure



Profile Sketch

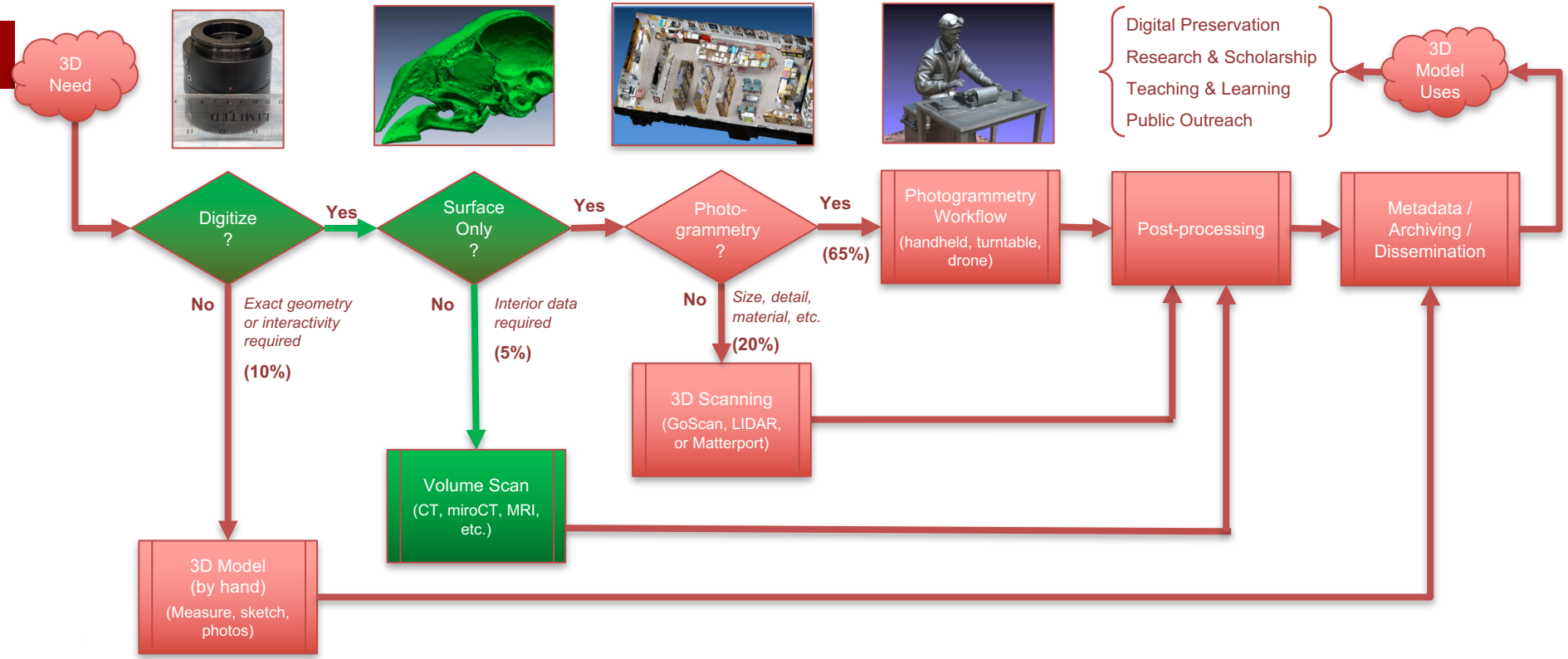


Revolve



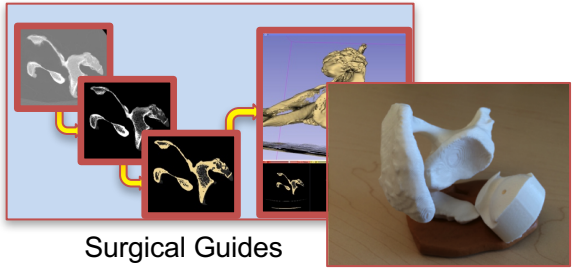
Chamfer

3D Digitization – How? (Choosing between techniques)

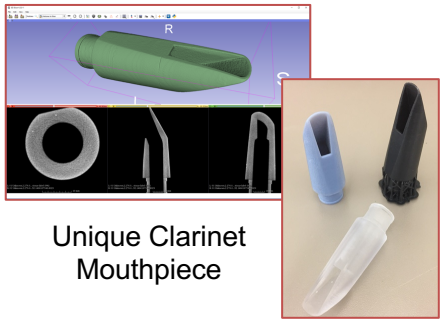


Hardware-Based Volumetric Scanning

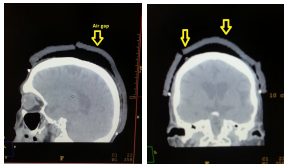
- CT, MicroCT, CBCT, MRI



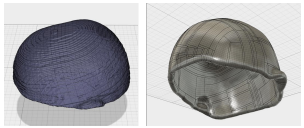
Surgical Guides

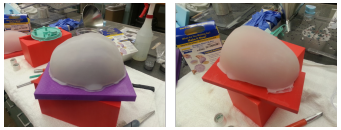


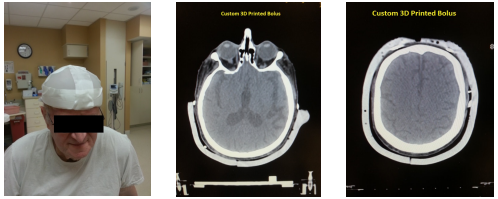
Unique Clarinet Mouthpiece



Improved Radiation Bolus

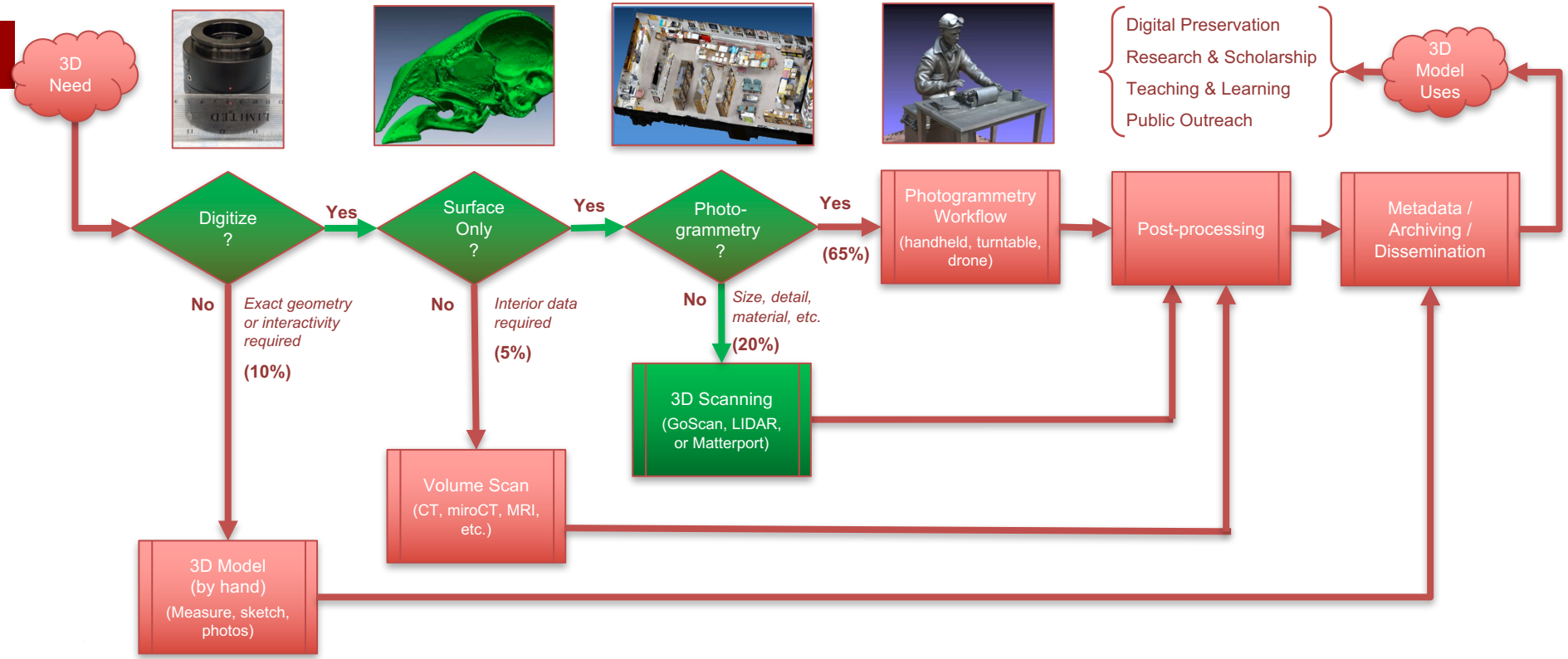






Data Capture: Indiana Institute for Biomedical Imaging Sciences - Preclinical Imaging

3D Digitization – How? (Choosing between techniques)



Hardware-Based Surface Scanning

- Structured light scanners
- Laser time-of-flight scanners
- Specialty for large spaces

3DMD ($45K)

Leica LIDAR (> $50K)

Matterport ($4K)

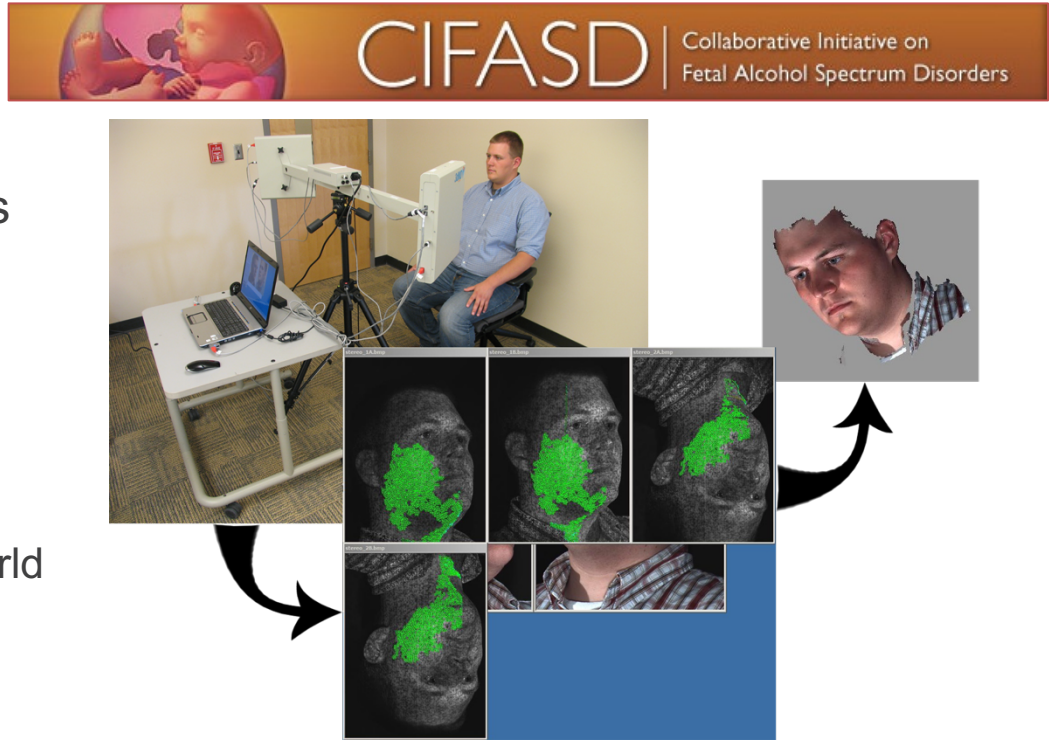
NextEngine ($3K)

Minolta ($30K)
(Retired)

Go!Scan ($25K)

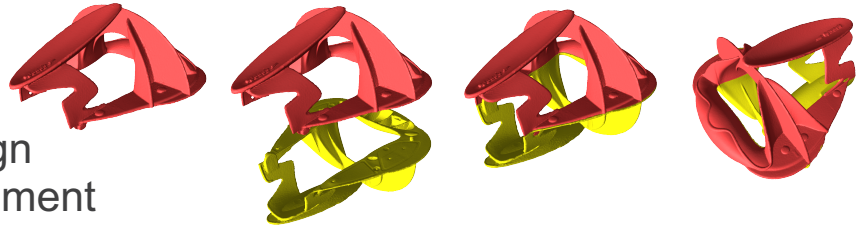
3D Scanning – Collaborative Initiative for FASD

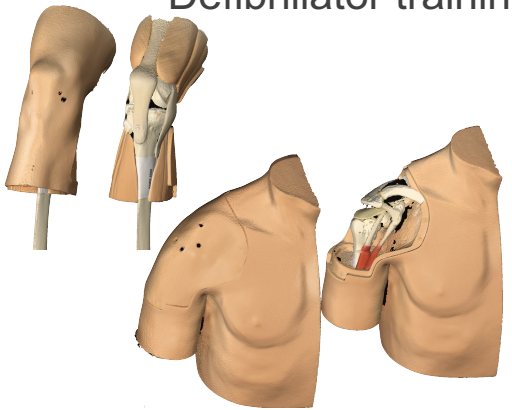
- FASD = Fetal Alcohol Spectrum Disorders
- NIH-NIAAA funded for 15 years
  - 22 partner institutions
  - 6 countries
- 3D facial imaging core led by IU School of Medicine & RT
  - Locations across US & the world
  - Over 5,000 patients scanned
  - Many longitudinal subjects

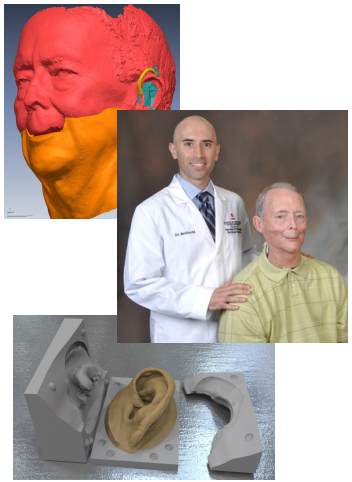


Example Projects

- Analysis, Redesign, Repurpose
  - Swim trainer reconstruct and redesign
  - Surgery training equipment enhancement
  - Travis Bellicchi and the “Shirley Method” for Prosthodontics
  - Engine pushrod analysis
  - Defibrillator training app







LIDAR scanning example

- Bethel African Methodist Episcopal Church (Indianapolis)
- IUPUI School of Informatics and Computing Project – Zeb Wood, et. al.
- https://comet.soic.iupui.edu/bethel/index.php/

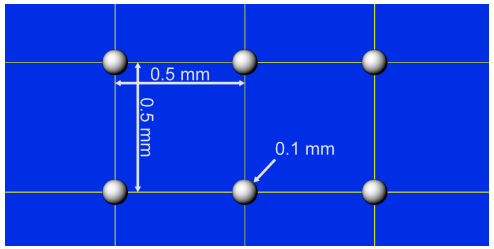
LIDAR reference scan

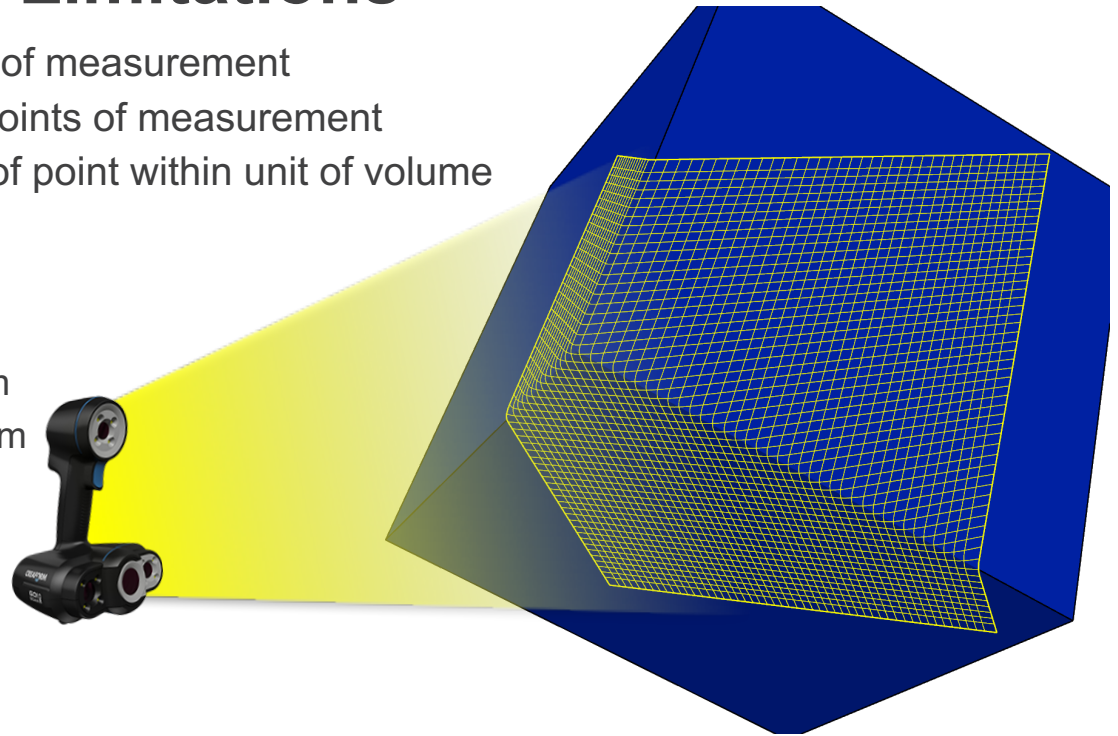
3D modeled reconstruction

with materials & textures

Hardware-Based 3D Scanning Understanding the Limitations

- Accuracy: Certainty at the point of measurement
- Resolution: Distance between points of measurement
- Volumetric Accuracy: Certainty of point within unit of volume
- Example:
  - Creaform Go!Scan 50
  - Accuracy: 0.1 mm
  - Resolution: 0.5 mm maximum
  - Volumetric accuracy: 0.3mm/m

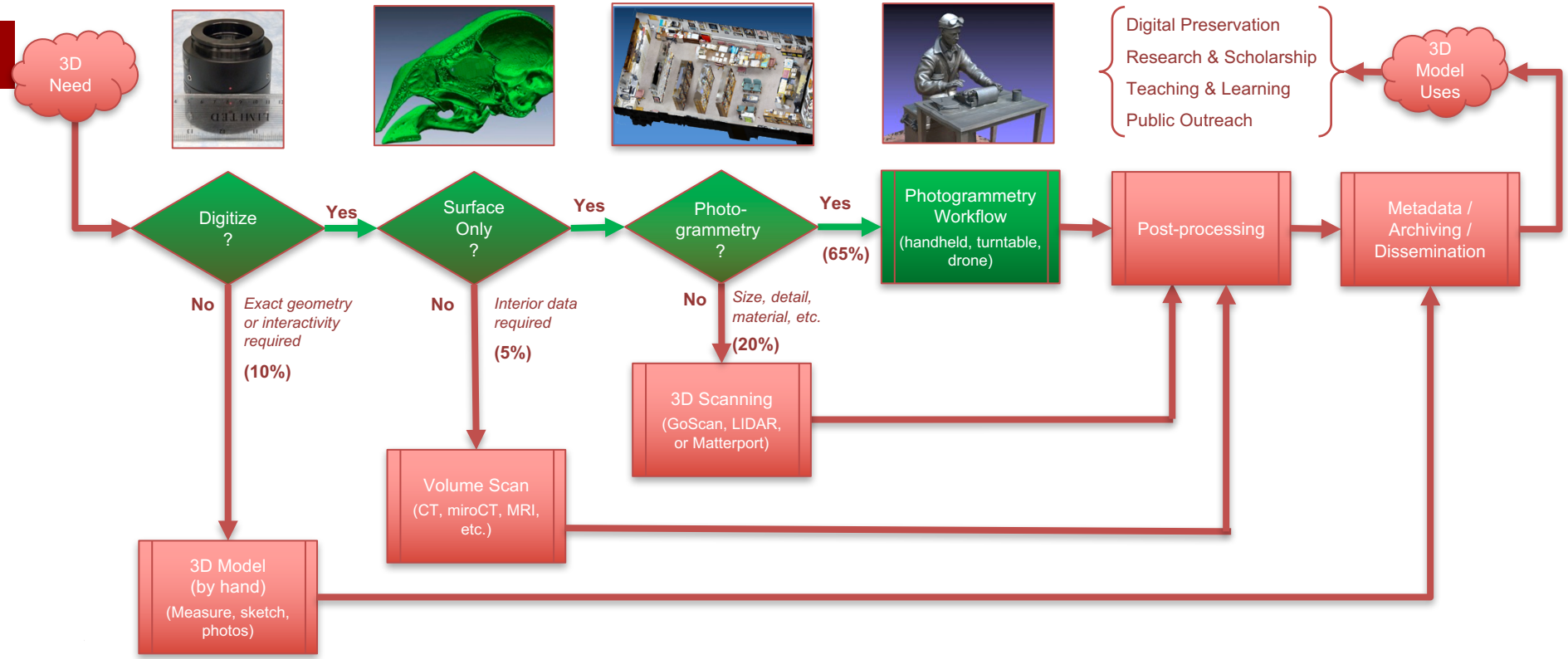




Hardware-Based 3D Scanning Understanding the Limitations

- Hardware Scalability
- Limited Color

3D Digitization – How? (Choosing between techniques)



Software-based Photogrammetry

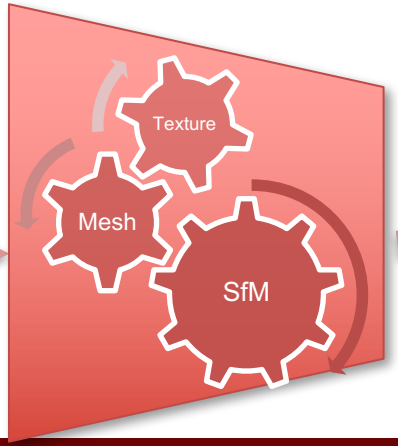
- A method for extracting three-dimensional (3D) models or measurements of an object, environment, or terrain from a set of standard two-dimensional (2D) photographs
- Applicable to a broad range of academic disciplines, including cultural heritage, architecture, paleontology, and geospatial
- Results in high computational complexity and large data sizes

Photogrammetry – General Workflow

Life-size bronze statue
(by Tuck Langland)

300+ photographs
capturing all angles
and details

Photogrammetry
& 3D post-processing
workflows



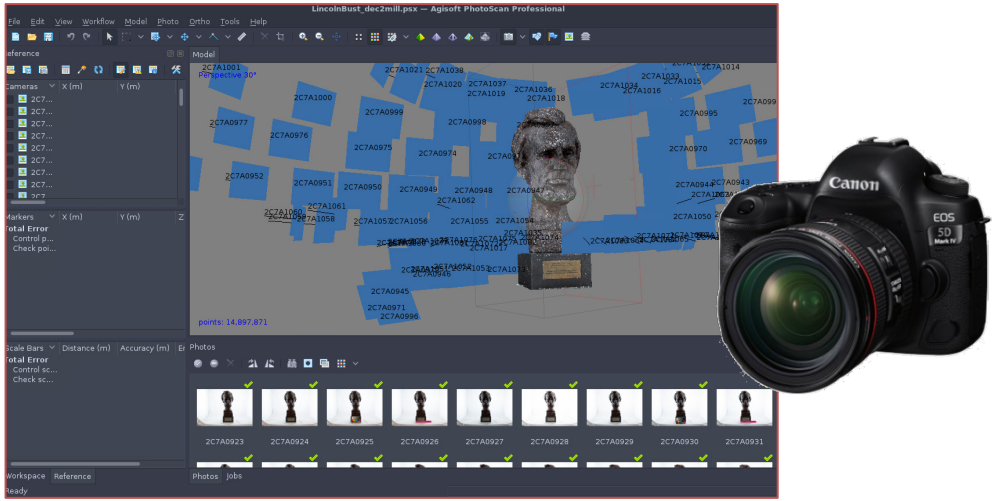
Texture-mapped 3D model

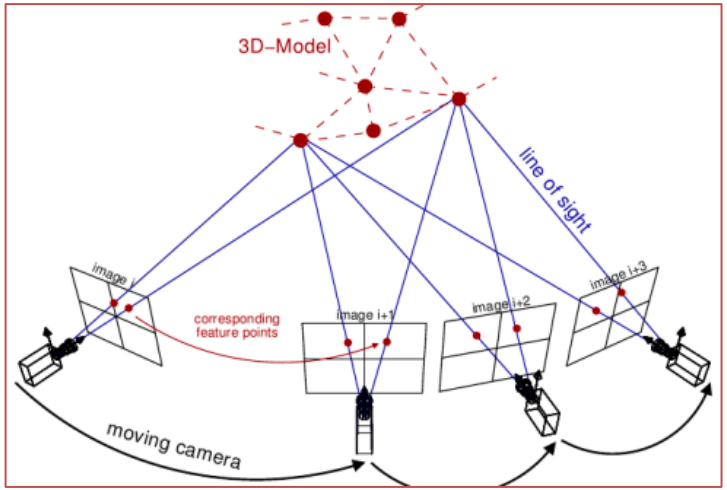
Photogrammetry – A word about photography

- Supports many types of cameras & rigs
- Key issues:
  - Quality
  - Coverage
  - Consistency
  - Lighting
  - Background
- Can work with video and integrate depth image data

Photogrammetry for Surface Reconstruction

- Capture series of 2D images
- Use structure from motion techniques to extract 3D surface points





www.wur.nl

Example Projects

- Cultural Heritage
  - Ruth Lilly Medical Library & Leo J. McCarthy Collection
  - Treasures of the Lilly Library
  - IU Bronze Statues & other IU artifacts

Scalable Photogrammetry

Why HPC for Photogrammetry?

- Algorithm complexity → hours-days of computation for small-medium photo sets; weeks for larger data sets on a good workstation

Coordinates:

- *(X, Y, Z)* - point in the local camera space
- *(u, v)* - projected point in the image plane
- *w, h* - image width and height

Camera:

- *f* - focal length
- *cx , cy* - principal point offset
- K_1 , K_2 , K_3 , K_4 - radial distortion coefficients
- P_1 , P_2 , P_3 , P_4 - tangential distortion coeffs
- B_1 , B_2 - affinity and non-orthogonality coeffs

Solve these systems of equations for every point on every photos in photo set:

$$x = X / Z$$

$$y = Y / Z$$

$$r = sqrt(x^2 + y^2)$$

$$x' = x(1 + K_1 r^2 + K_2 r^4 + K_3 r^6 + K_4 r^8) + (P1 (r^2 + 2x^2) + 2P_2 xy) (1 + P_3 r^2 + P_4 r^4)$$

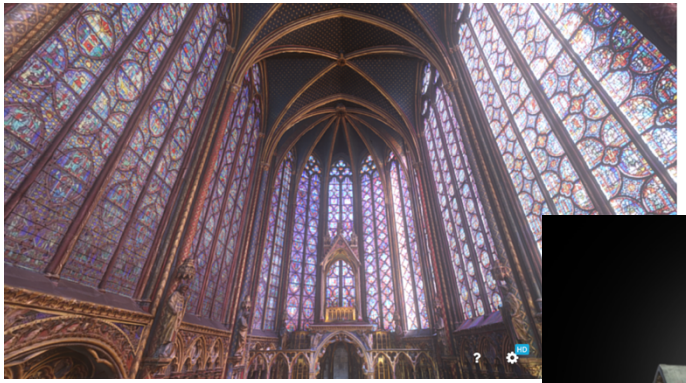
$$y' = y(1 + K_1 r^2 + K_2 r^4 + K_3 r^6 + K_4 r^8) + (P_2 (r^2 + 2y^2) + 2P_1 xy) (1 + P_3 r^2 + P_4 r^4)$$

$$u = w * 0.5 + cx + x'f + x'B1 + y'B2$$

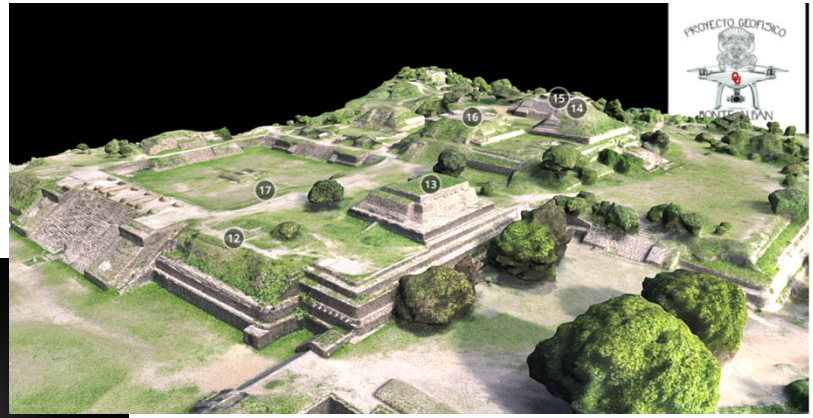
$$v = h * 0.5 + cy + y'f$$

Scalable Photogrammetry

Large objects & spaces → very large number of photos



Architectural Interiors & Exteriors
(Matthew Brennan)
→ ~300-1000+ photos each



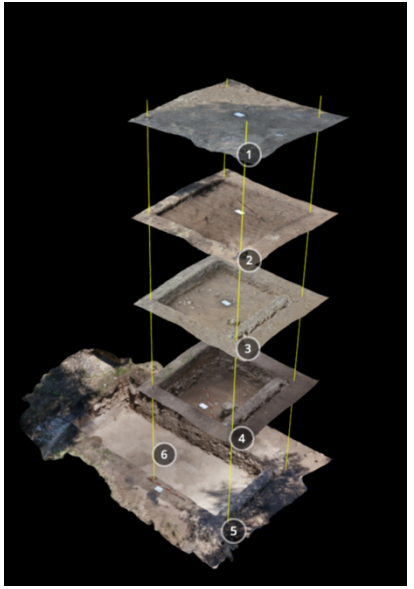
Monte Albán Geophysical
Archaeology Project
(Alex Badillo)
→ 14,000+ photos
→ ~30 compute hours

Scalable Photogrammetry

Large collections → many, many data sets

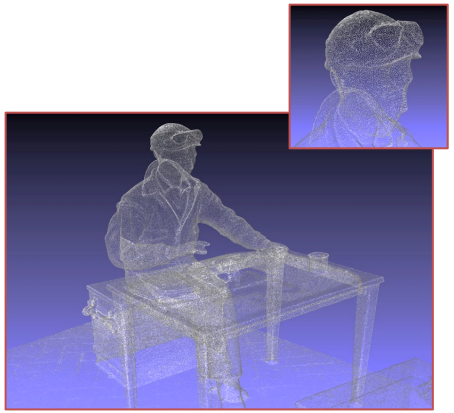
IU Center for Biological Research Collections (Gary Motz)
→ 2M+ objects, 100K+ unique

IU Virtual World Heritage Lab (Bernie Frischer, M. Brennan, et. al.)
→ Uffizi, other statuary
→ archaeological recreations



Cosa Archaeological Site (Matthew Brennan)
→ Temporal series

Photogrammetry Processing – Steps



1. Align photos & generate point cloud → 2. Build dense point cloud → 3. Build mesh → 4. Build texture

Photogrammetry Software

Commercial

- PhotoScan by Agisoft
- Reality Capture by CapturingReality
- 3DF Zephyr by 3DFlow
- AutoDesk ReCap / ReMake / Memento
- etc.

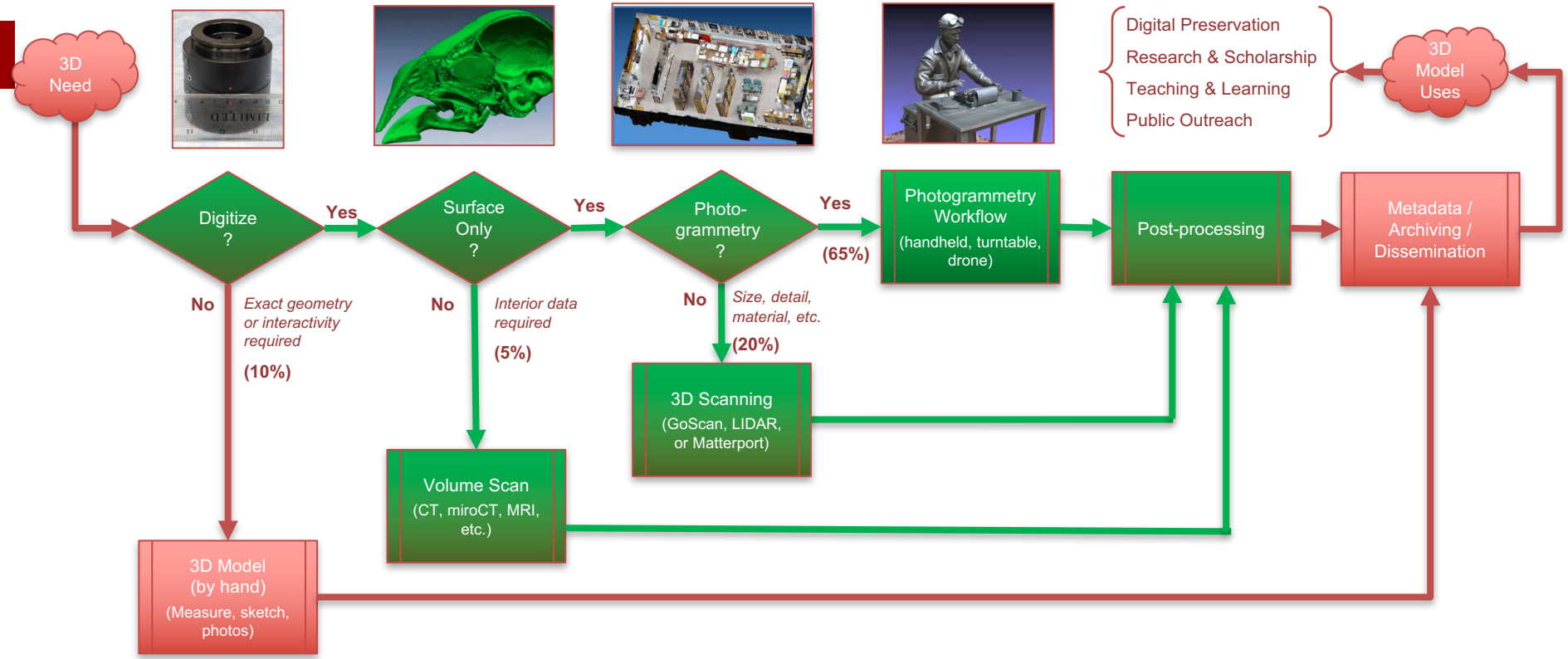
Open source

- Multi-View Environment (MVE)
- Multiple View Stereovision (OpenMVS)
- Open Multiple View Geometry (OpenMVG)
- Visual Structure From Motion (VisualSFM)
- COLMAP
- MicMac
- Alicevision Meshroom

Comparing 3D Digitization Options

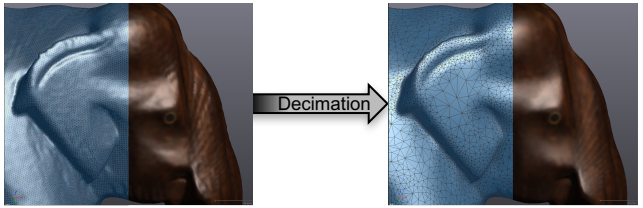
Surface Scanning	Photogrammetry	Volumetric Scanning
Pros	Pros	Pros
• Greater spatial accuracy (<1mm) • Less time on site • Real-time feedback on quality • Less post-processing time • Less chance of user error/failed scan	• Affordable equipment • Highly portable • Underwater and aerial (drone) compatible • Potential to reprocess for greater accuracy • Better color capture • Potential for more detail capture • Scalable	• Captures internal structures • Very high resolution (~9um)
Cons	Cons	Cons
• Expensive equipment • Must upgrade equipment to achieve future gains	• Lower spatial accuracy • Lengthy, computationally expensive post-processing ***(getting faster)*** • Challenges of processing in the field (laptop) • Potential inadequacy/failure of photo set • More time on site	• Costly scan • Cumbersome Isosurfacing • Some materials cause noise • Size limitations • Object must be brought to scanner

3D Digitization – How? (Post-Processing)



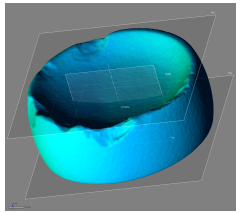
Post-Processing Techniques

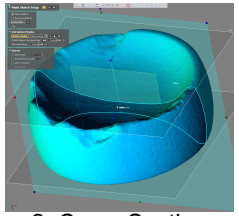
- **Polygonal decimation**: reduce number of polygons for interactive apps
- **Polygonal mesh healing**: eliminate holes and cross-facing polygons to achieve water tight mesh
- **Color preservation**: Re-project source color when mesh healing destroys texture UV map

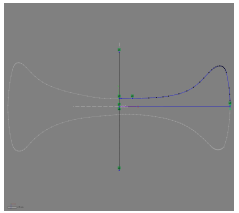


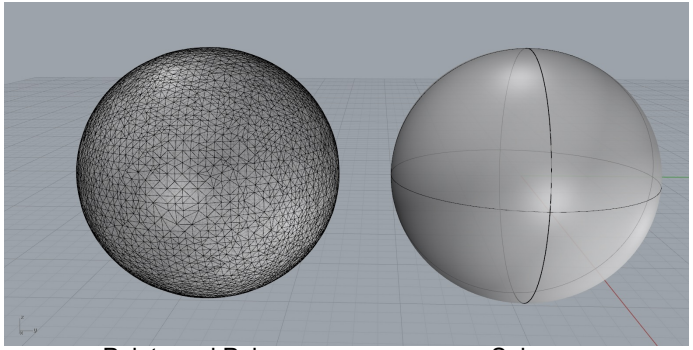
Post-Processing Techniques

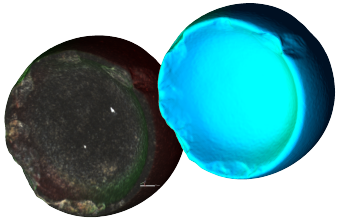
- **Parameterization**: extracting the parameters that mathematically define geometric objects
- Example: Chunkey Stone Scan Data

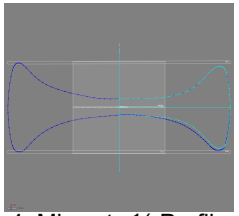

1. Extract Parameters

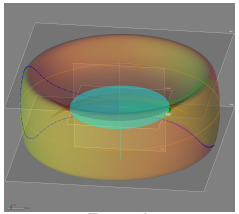

2. Cross Section

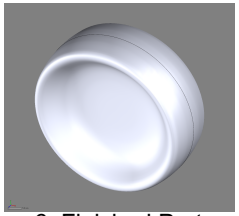

3. Sketch ¼ Profile

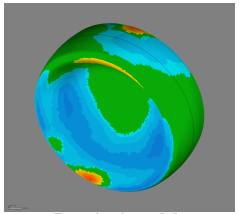

Points and Polygons Sphere




4. Mirror to ½ Profile

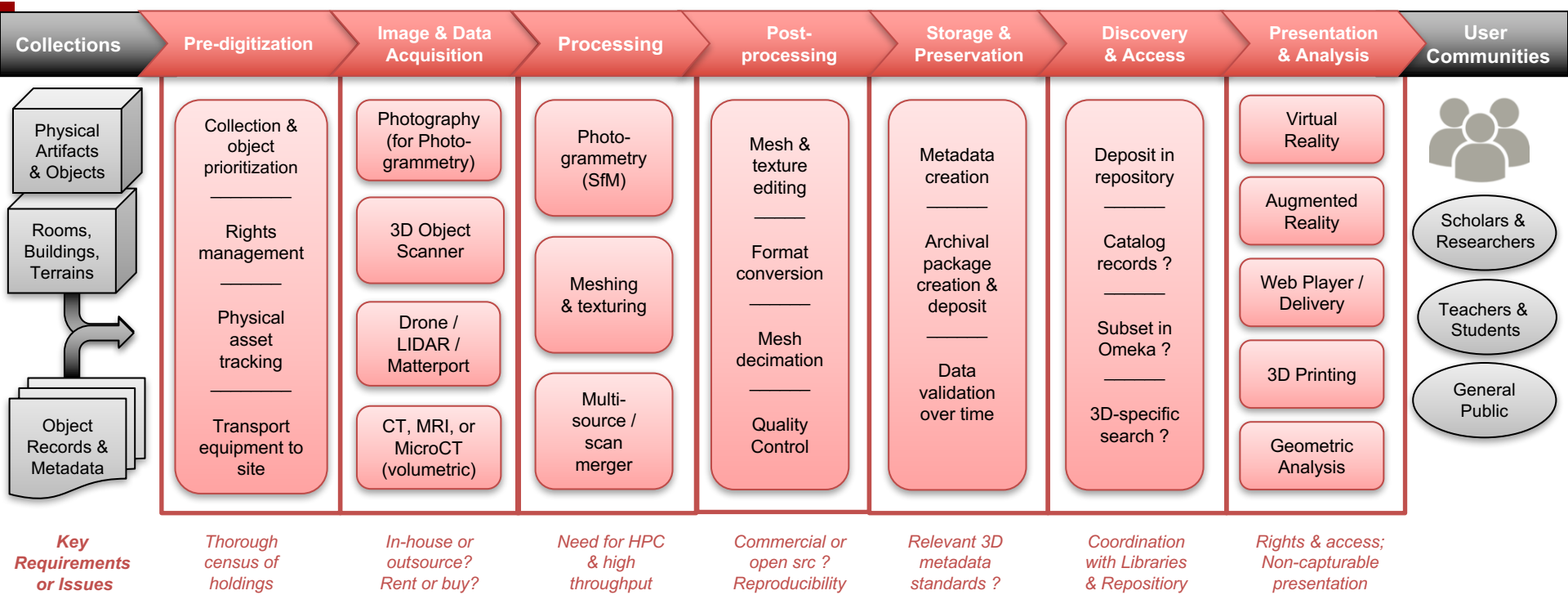

5. Revolve


6. Finished Part


7. Deviation Map

A Complete 3D Digitization Workflow

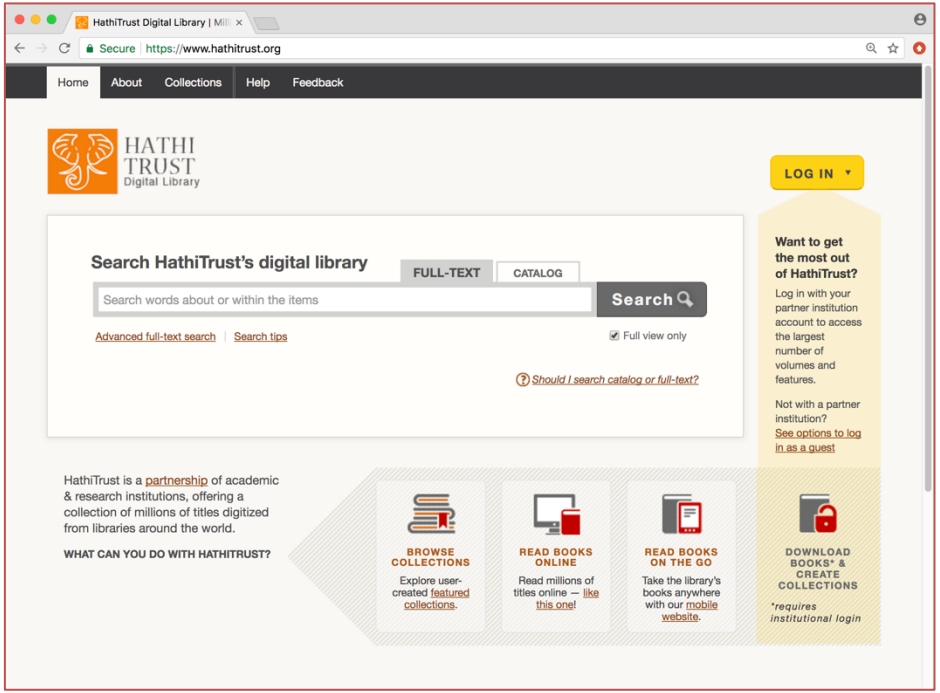
3D Digitization Workflow



(by E. Wernert; adapted from IU MDPI Workflow)

HathiTrust & HathiTrust Research Center

- HathiTrust: 2008
  - Google Books project & 13 CIC universities
  - 16.7M volumes; 6.2M in public domain
- HTRC: 2011, IU & UIUC
  - Enable very-large scale text mining and analysis
  - Non-consumptive research methods for in-copyright works
- Issues
  - **Non-consumptive methods**, rights mgmt, metadata quality, search & access, dirty OCR, biases in collection, …



IU Media Digitization & Preservation Initiative

- University-wide initiative; 2012 survey of holdings: over 750,000 items
- Deterioration of media; obsolescence of formats or playback equipment
- **Phase 1**: 325,000 audio & video (93% done); **Phase 2**: 25,000 films (24%)
- Partnership with Memnon (Sony): high-throughput formats: ~85%
- IU technicians: 1:1 and specialty formats: ~15%

Pre-digitization

Before audiovisual media objects can be digitized they need to go through a number of preparatory steps.
Continue reading »

Digitization

MDPI is pursuing a dual strategy for the digitization of IU recordings.
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Post-digitization

After files are digitized, they must be checked and transcoded (converted to other formats suitable for access).
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Quality control

Quality assurance (QA) and quality control (QC) are key steps in the MDPI workflow.
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Storage & preservation

Audio and video content digitized in both the Memnon and IU digitization facilities is stored in IU's Scholarly Data Archive (SDA).
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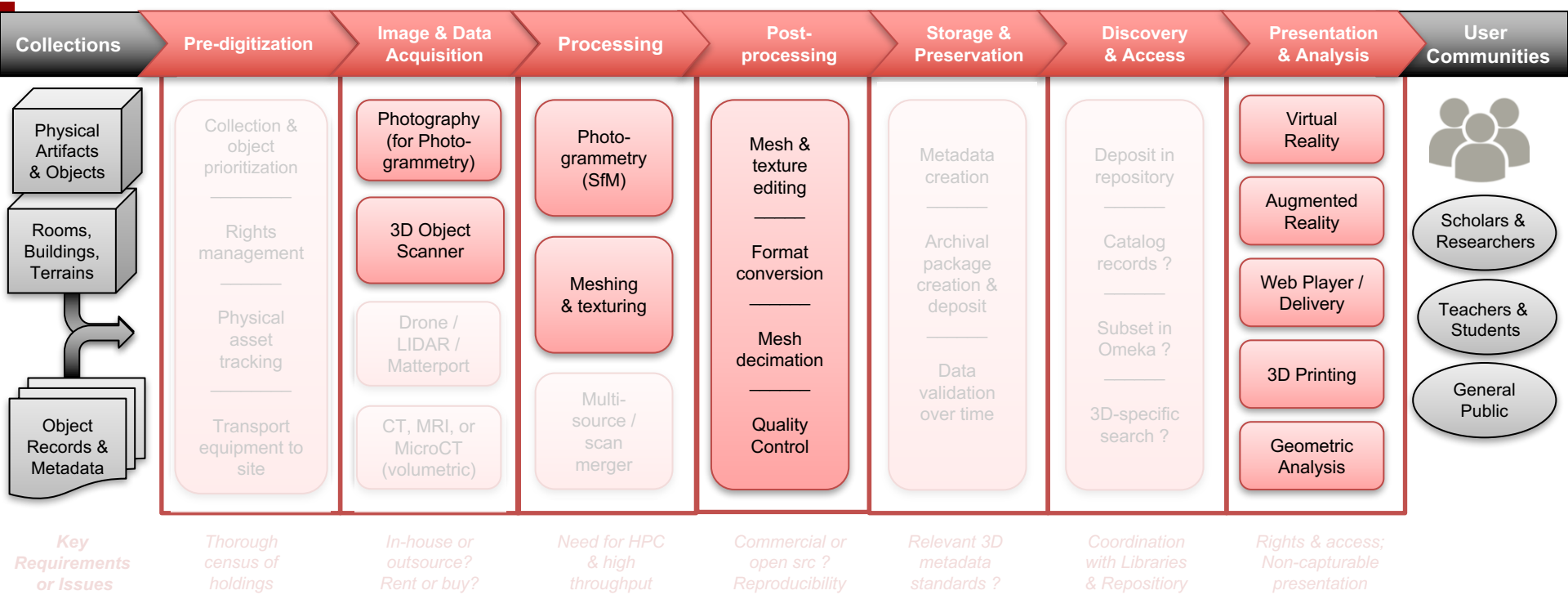
Discovery & access

IU is using the Avalon Media System to provide online access to audio and video content digitized as part of MDPI.
Continue reading »

3D Digitization Workflow



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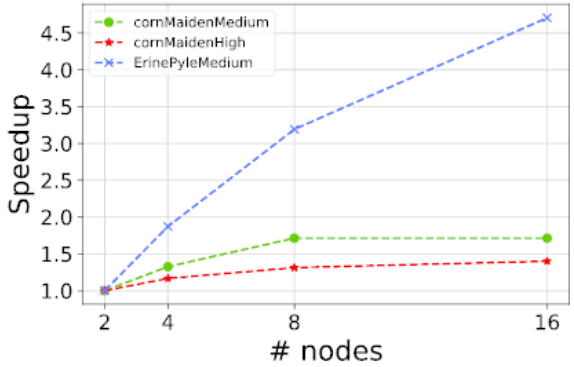
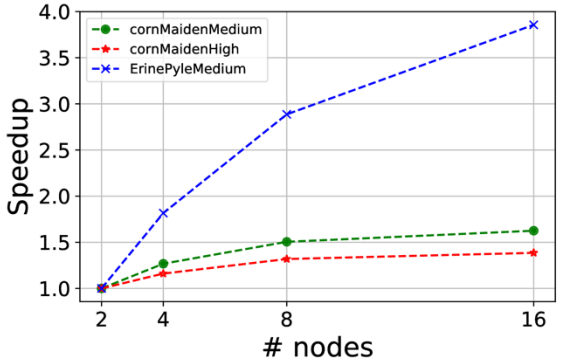
Experiences & Results

Experiences with IU Photogrammetry Workflow

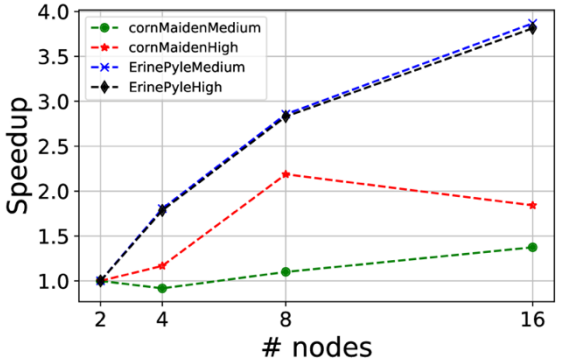
Multi-node scaling analysis (with PhotoScan)



Karst



BigRed II



Carbonate

Experiences with IU Photogrammetry Workflow

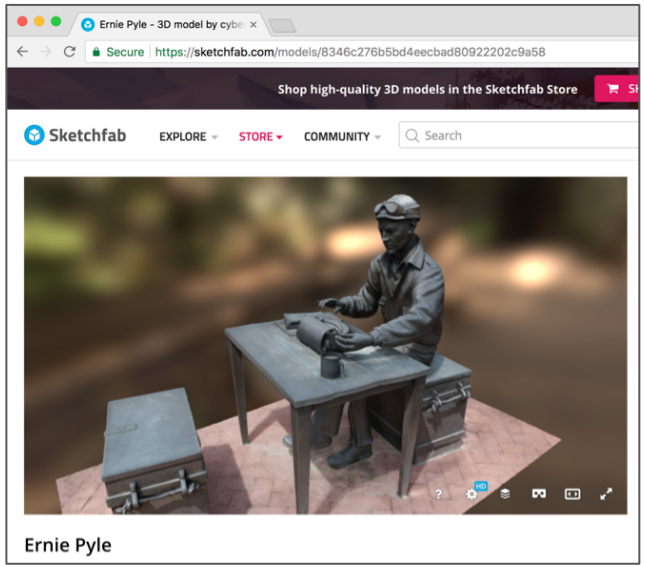
- **# of Jobs – 919** (Spring Semester 2018)
  - Many run by students
- Runtime in mins
  - mean: 140, **median: 27**, max: 1800, min: 1
- Requested # nodes
  - mean: 6, **median: 4**, max: 30, min: 1
- # of photos
  - **max: 14,261**, min: 63

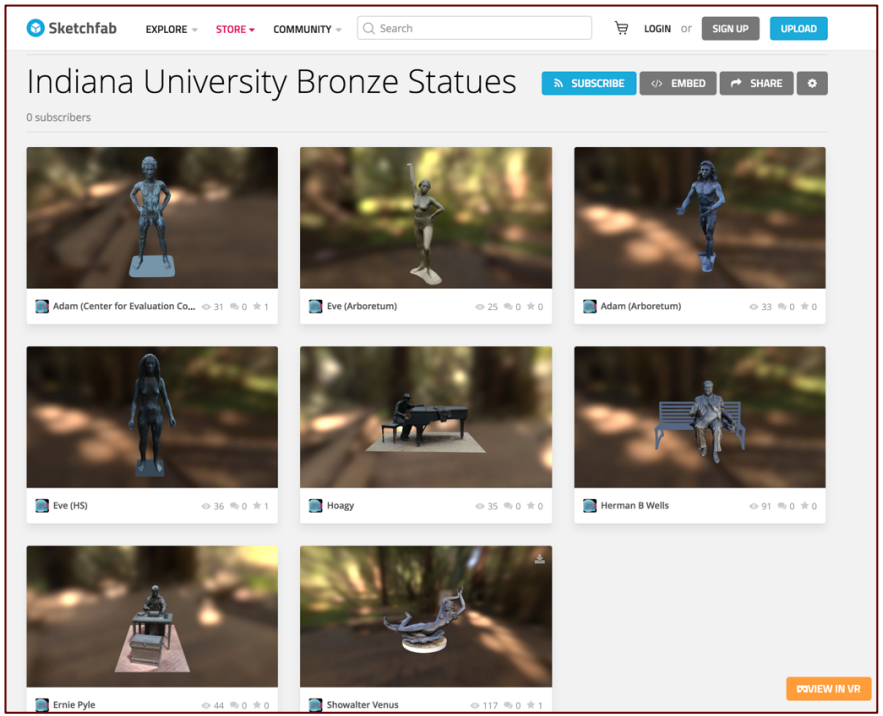
Expanding our workflow

- Initial benchmarking of PhotoScan on Stampede2 (TACC)
  - Comparing KNL and Skylake portions of system
  - Per-node memory limitations can be an issue
- Open source tools in the works
  - MVE, OpenMVS, OpenMVG, etc.
- AliceVision running on Google Cloud Platform
  - Many newer open source packages require modern GPU support
  - GPU support in the works for IU

Web collection on SketchFab

- Bronze Statues of IU

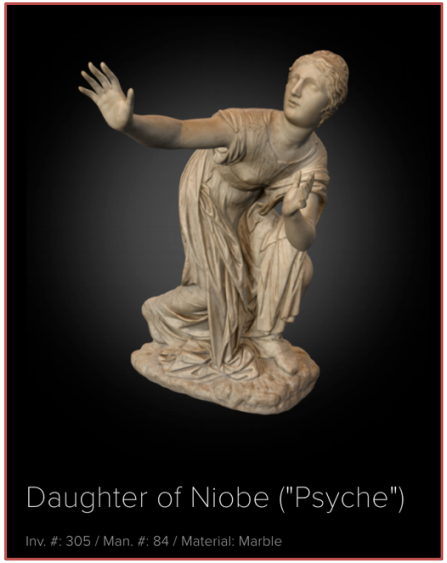




https://sketchfab.com/cyberdh/collections/indiana-university-bronze-statues

Web collection on SketchFab

- Uffizi Digitization project
- https://www.digitalsculpture-uffizi.org/



Identifiers

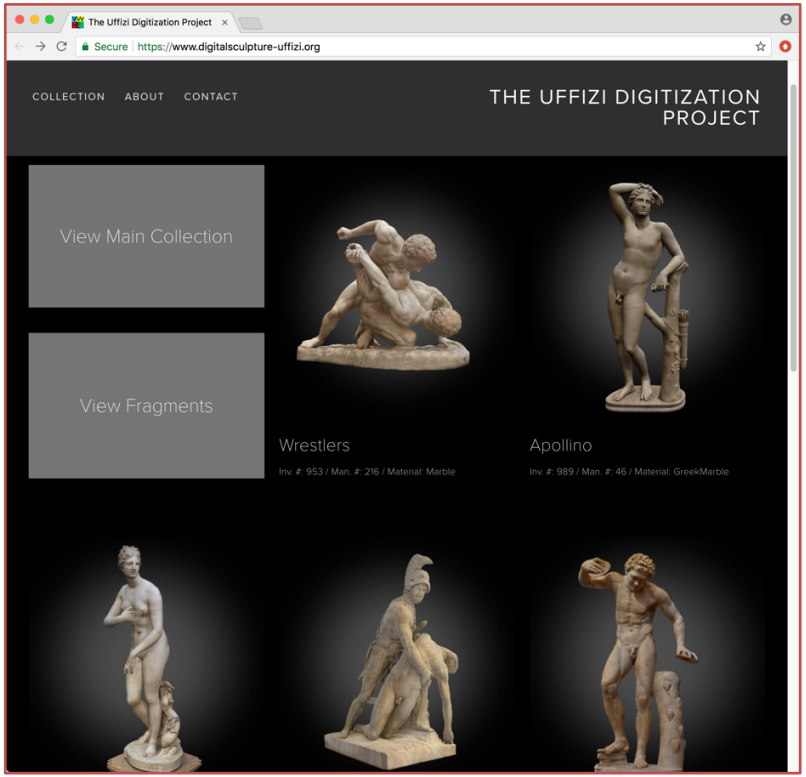
- *Title/Name:* "Tormented Psyche" Niobid
- *Inventory:* Inv. 1914 n. 305
- *Mansuelli:* I.84

Characteristics

- *Format:* Statue
- *Artist:* Roman copy of a Greek original attributed to Scop
- *Date:* Roman copy of a Greek original dated to 4th centu
- *Materials:* Marble
- *Inscription:* n/a
- *Dimensions:* W 79 cm; L 46 cm

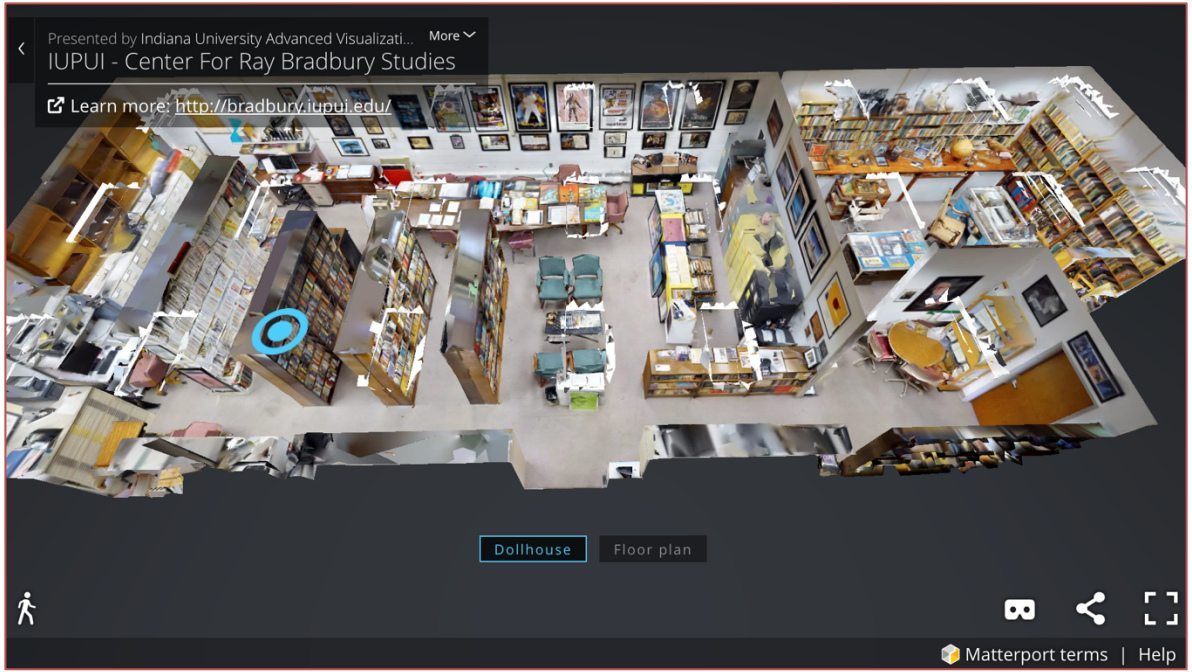
Paradata

- *Camera:* Nikon D810 with Nikkor 24-85mm F/2.4-4 lens,
- *Photographer:* Whitney Johnson
- *Reconstruction Software:* RealityCapture, ZBrush
- *Modeler:* Whitney Johnson



Web collection on Matterport

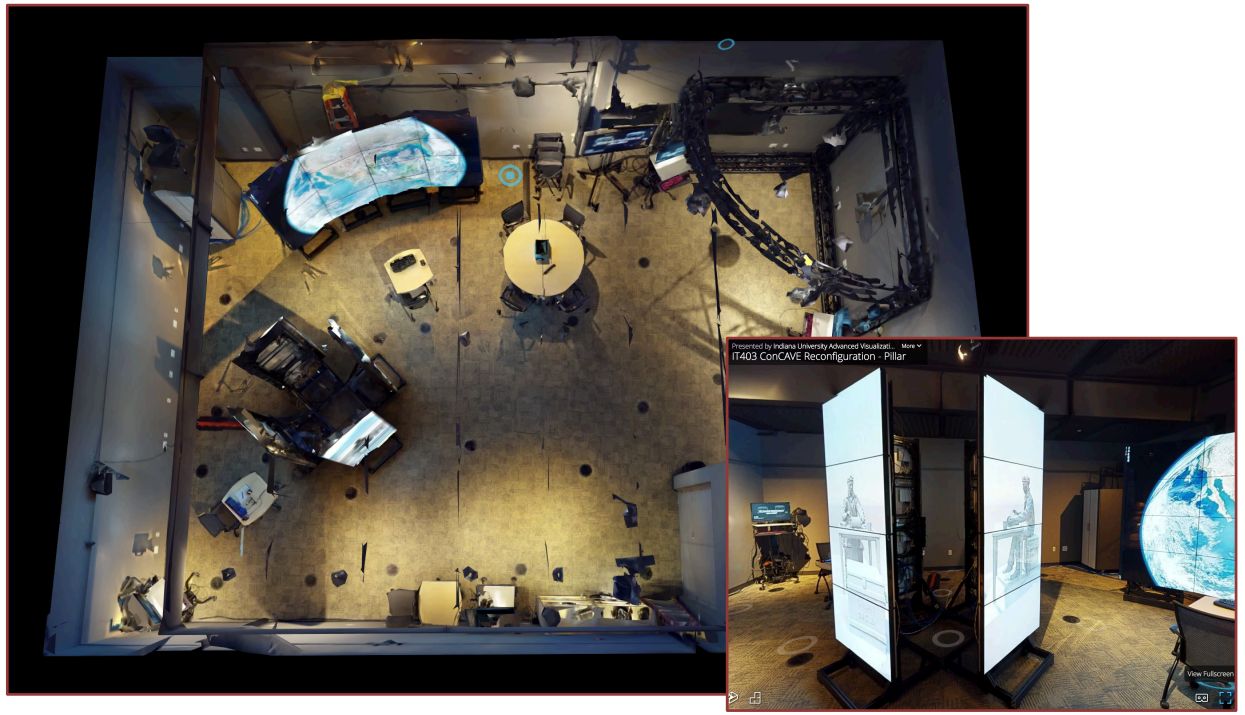
- Center for Ray Bradbury Studies
- Cavanaugh Hall, IUPUI



https://my.matterport.com/models/2ds5iarQnk3?section=media&mediasection=showcase

AVL Flagship Facility (NEXT Lab @ ICTC)

- NEXT = New, Emerging, and eXperimental Technologies
- IQ-Wall can be reconfigured (e.g., pillar configuration for SC'18)



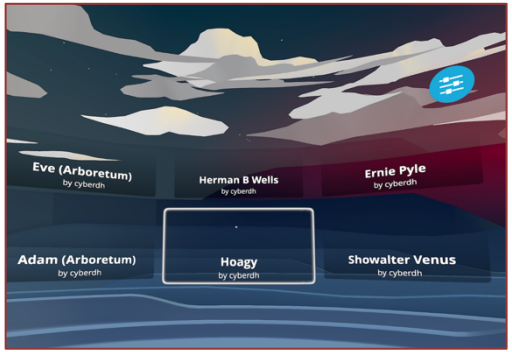
https://my.matterport.com/show/?m=KPN2Z914u6i

Flagship Facility – NEXT Lab

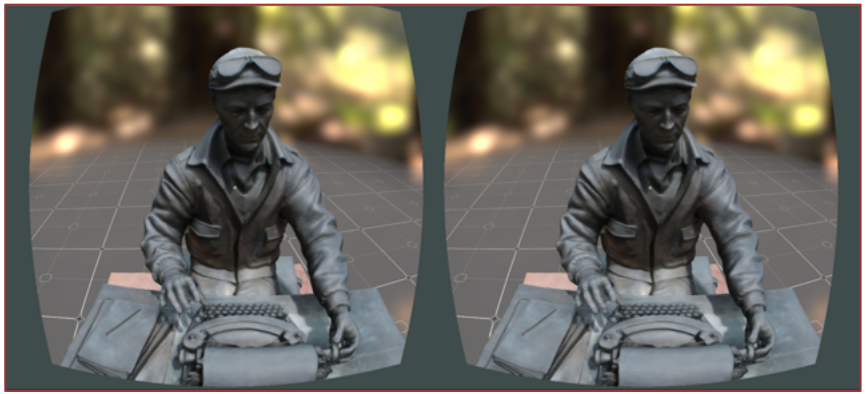
NEXT = New, Emerging, and eXperimental Technologies

Virtual Reality applications

- Virtual objects, virtual museums, site visits
- Issues:
  - App development (role of Web VR, existing apps)
  - Decimation: quality vs. speed



Matterport – Indiana Medical History Museum



Sketchfab – Ernie Pyle – Phone app or WebVR

Augmented Reality applications

- Augmented posters, physical exhibits, augmentation of real world, simulation & training, just-in-time documentation
- Issues:
  - App development (role of Web tech, existing apps)

Paleontology scans

3D modeled CAD files

Procedural training

3D Printing






Conclusions &
How to apply to your work

Conclusions

- 3D digitization is important and valuable for
  - digital preservation and documentation
  - research, scholarship, education, and outreach
- For large collections, it should be done systematically and at scale
  - should also incorporate data management and metadata solutions
- Even for one-off research projects…
  - standardization improves data sharing and reproducibility
- Photogrammetry is the most accessible / broadly applicable 3D digitization method
  - but it requires coordinated cyberinfrastructure resources to perform at scale
- Properly managed and acquired 3D assets are just the beginning
  - many relevant toolchains: VR, AR, Web, 3D print, etc.

Ongoing Work

- Implement additional, open-source photogrammetry packages
- Leverage national cyberinfrastructure (XSEDE) to open availability to all
  - Jetstream (IU, TACC)
  - Stampede2 (TACC)
  - GPU-enabled systems
- Expand documentation & implementation of other stages of the pipeline
  - photography, post-processing, dissemination methods, etc.
- Develop resources & interfaces for the national community
  - Community allocations & Jetstream images – 3-6 months
  - Science gateway / portal – 18-24 months

3D digitization & your work @ IU

- Available to all – at no charge
  - Initial digitization consultation (choosing a path to 3D) – AVL or CyberAH
  - Photogrammetry w/ Photoscan on Carbonate + photography best practices
  - Post-processing workflow documentation
    - Currently: VXElements, Zbrush, Geomagic, Meshmixer, 3D Slicer
- Limited availability – scheduling & training required
  - 3D structured light scanner & computer (Creaform GoScan + VXElements)
  - Matterport scanner for rooms & building interiors
  - Advanced photogrammetry photography kit (light tent, lights, turntable, etc.)
- Working with multiple objects…
  - Single object or very small collection – we may do it for you
  - Multiple objects or open-ended collection/project – we train you and provide resources

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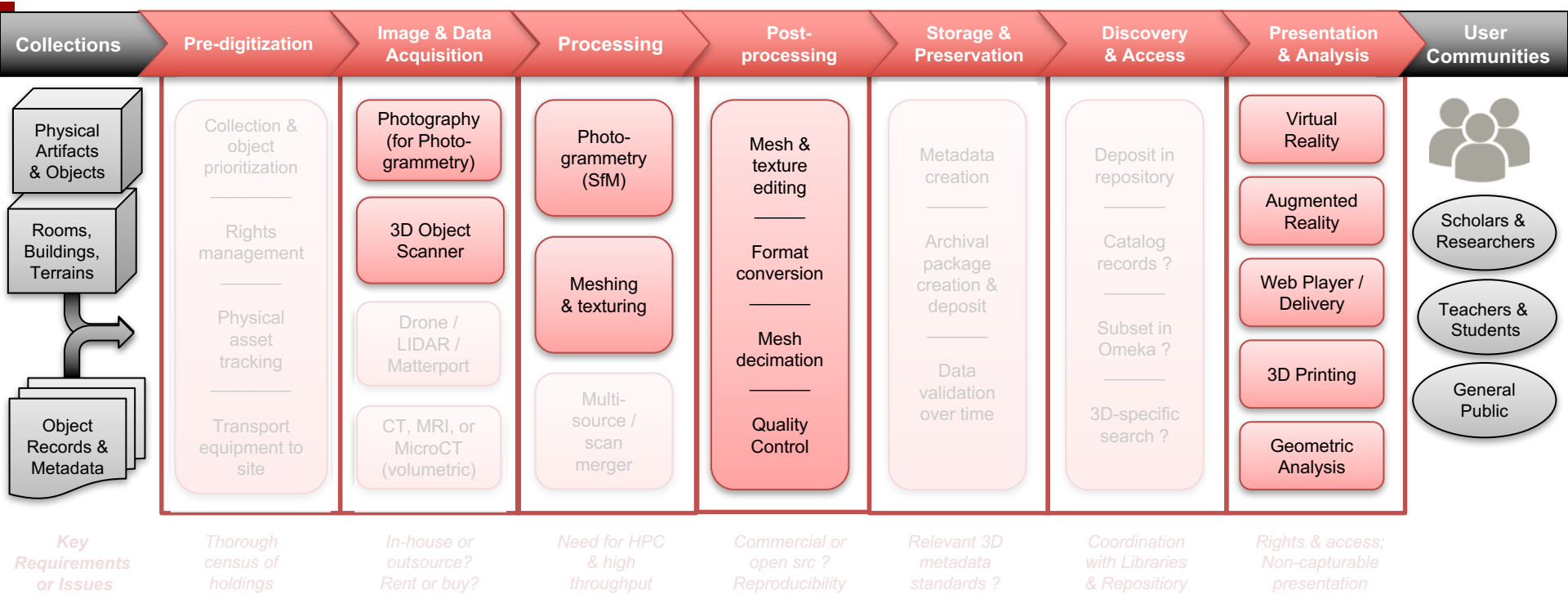

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Estimated amount of effort required (per object)

- Photogrammetry:
  - photography (15-30 minutes) – your own equipment on your own schedule
  - processing (10-15 min interaction + 1-8 hours unattended processing) – on IU HPC systems
- Scanning:
  - Scanning and processing - 25-45 minutes; based on shared scanner schedule/availability
- Post-processing
  - Clean-up: 20 minutes / 2 hours / 2+ days (min / avg / max)
    - depends on object complexity, quality of digitization, and desired quality of final model
  - Metadata & data management: TBD, estimated 15-45 min
- Utilization
  - Sketchfab / Web repository – 5 minutes - upload & config
  - VR/AR - 10 minutes to several weeks, depending on level of customization
  - 3D print – 30 minutes to several hours, depending on object complexity & print technology
  - Geometric analysis – 0 minutes – ready to use in most analysis packages

Acknowledgements

- Photogrammetry – Tassie Gniady, Katie Chapman, Bill Sherman
- HPC Photogrammetry – Guangchen Ruan, James McCombs
- Photography methods – Chris Eller, Ed Dambik
- 3D Scanning – Jeff Rogers
- 3D Post-processing – Jeff Rogers, Tyler Jackson
- IU Virtual World Heritage Lab – Matthew Brennan, Bernard Frischer, Gabriella Guidi
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- Researchers: Alex Badillo, Gary Motz, Matthew Brennan, Stacie King, Lilly Library, Travis Bellicchi, Brian Overshiner

Thank you!

For questions or more information on:

Photogrammetry: cyberdh@iu.edu

3D scanning & VR: vishelp@iu.edu

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FULFILLING *the* PROMISE